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Renewable energy sector in Belarus: A review

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ABSTRACT

Belarus (BY) faces broad needs for energy security enhancement, energy diversification, and improvements in the state of the environment. Being the 13th largest importer of natural gas for energy BY has very limited energy resources of its own. Maximum reduction of energy imports is among the strategic tasks of raising the efficiency of Belarus' economy. The task fulfillment is possible through creation of a national infrastructure conductive to increasing the share of local and renewable sources of energy (RES) in heat and power energy production.

BY's geographic location has several advantages for extensive use of most of the renewable energy (RE) and bioenergy sources. However, information on existing RE sector for the second-largest landlocked country in Europe is still hardly available for a wider audience of researchers working in the field of economic, environmental, political, planning and social aspects of energy supply in global proportions.

The review on the renewable energy sector in BY so far has tried to give the background for RES, to describe their occurrence and conditions for using them, leading up to a discussion of the role of renewable energy in current and future energy systems, depending on a path of economic transition, social values, availability, and economic rules used to judge the viability of competing solutions. To ensure a simple, comprehensible and transparent presentation of the different available options of using RE for the provision of heat and power, the individual chapters describing the various renewable energy potentials and contribution options have been similarly structured whenever possible and sensible.

Contents

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1. Introduction

Being the 13th largest importer of natural gas for energy, Belarus (BY) has been showing a big interest and optimism regarding striving to develop a more secure and sustainable energy sector with a special emphasis on RE for a long time [1,2]. Maximum reduction of energy imports is among the strategic tasks of raising the efficiency of Belarus' economy. The task fulfillment is possible through creation of a national infrastructure conductive to increasing the share of local and alternative sources of energy in heat and power energy production [3,4].

However, information on existing RE sector for the second-largest landlocked country in Europe is still hardly available for a wider audience of researchers working in the field of economic, environmental, political, planning and social aspects of energy supply in global proportion. The specific nuances of transition economy path chosen by Belarus, so-called 'Belarusian Model', and 'Eastward-biased' policy propagated for many years [5]—these are the underlying factors, which have limited an ability to study Belarusian RE sector at international level, with a view towards the sustainability of it is growth. This is a notable knowledge gap, as a need for wider information diffusion is recognised as one of the key determinants for the efficient transformation of traditional energy systems towards energy systems based upon alternative energy sources.

Sustainable environment and energy are among key priorities worldwide [6–12] and renewable energy and energy efficiency initiatives will continue to be a priority in BY [1,2,13]. At present, the Republic of Belarus is in the process of implementing the 'Target electricity and heat provision program for achieving at least 25% of industrial production with the use of local types of fuel and alternative sources of energy by the year 2012' [3]. In order to provide 25% of electricity and heat with the use of local energy and fuel resources, it is necessary to increase their production up to 5.93 million tonnes of oil equivalent (Mtoe) per year, and to use the secondary resources such as heat energy, as well as primary resources from wind turbines and biogas in the amount of 0.82 Mtoe per year. In light of the above, the plans assume that by the year 2012 the use of local energy resources, including secondary heat resources, wind, solar and biomass energy, will be increased by 2.8 Mtoe [3,14].

The paper aims to deepen knowledge of existing RE sector and itis potential in Belarus, a country, that can produce and utilise significant quantities of RES for energy purposes. This work is essential to evaluating the role played by different types of alternative energy sources in the energy sector; assessing the share of biomass used for energy purposes; understanding the dynamics of bioenergy and renewable energy systems; and formulating sound policies.

2. Prerequisites for development of renewable energy in Belarus

2.1. Country's location and size, landscape geography, and climate conditions

The physical geography features of the country may however facilitate or hinder development of RE sector. For BY, most of them work in favour for extensive use of almost any kind of RES.

The territory of BY covers an area of 207.6 thousand km^2 (39%-forests, 2%-water, 43%-agricultural land, 16%-other land) thus being ranked 13th in size among the European countries and 5th in population among the Commonwealth of Independent States countries (CIS) [15]. BY has international borders with 5 sovereign states: Lithuania (678.819 km) and Latvia (172.912 km) in the North, Ukraine (1084.2 km) in the South, Russian Federation (1283 km) in the East, and Poland (398.624 km) in the West [14]. Country's territory is subdivided into 6 regions: Vitebsk, Minsk, Gomel, Grodo, Mogilev and Brest. Each of the region in its turn splits up into 16–22 districts. There are 110 towns and 101 urban-type settlements in BY [15]. The population of 7 towns numbers from 100,000 to 200,000; 7 cities have the population from 200,000 to 500,000.

Country's relief is predominantly flat and hilly: flat plains (sandy peat soils) of southeastern (S-E) BY cover an area of almost 60% of the territory, North West (N-W) highlands (loam soils) nearly 30% and tableland 10%. The average height is $\sim$160 m above sea level. Meadows occupy almost 3.3 million ha or 15.8% of the BY territory. Nearly 95% of them are upland meadows. According to their use, meadows are divided into pasture (1.54 million ha) and hey areas (1.76 million ha).

Climate of BY is moderate continental dominated by Atlantic cyclones. Winters are mild and humid with lengthy thaw periods and summers are temperate warm. The mean air temperatures for January and July ranges from – 4.4 °C to 18.8 °C in the S-E and from – 8 °C to 17 °C in the N-E, with the overall country's annual averages of 7.4 °C in the S-E and 4.4 °C in the N-E, respectively. The annual arrival of direct solar radiation to a horizontal face in clear sky conditions is 3500–4050 MJ/m^2 or 84–97 kcal/cm^2. The averaged annual precipitation is 550–650 mm for flat plains in the South and 650–750 mm for the hills of middle region. The vegetation period lasts on average about 184–208 day [15].

2.2. Aspects of economic transition

There is little doubt that landscape geography and climate conditions are one of the variables that impact the argued selection of RE technologies, although it is certainly never the deciding factor, since political and economic factors play the main roles in this matter.

BY's economy is an interesting case study for the specific transition path followed. After a period of fast reforms in the early 1990s, which led to price (but not wage) liberalisation, the state sector still represents an important part of the overall output [16,17]. Only about 30% of Gross Domestic Product (GDP) comes from the private sector. On the other hand, BY has always been one of the CIS countries with rapidest growth of RE sector, essentially because of the high level of human capital accumulation.

In accordance with the national accounts data the GDP of the Republic of Belarus at current prices totaled 137.4 trillion roubles in 2009, showing a 0.2% rise at constant prices as compared with 2008. The growth was determined by the increase in value added in the main branches of the economy: agriculture – 1.0%, construction – 11.3%, communications – 12.0%. In 2009 GDP per

capita amounted to 14457 thousand rubles and in comparison with 2008 grew 2.0% at constant prices [18].

A greater part of GDP in the country is assigned to consumption. Household final consumption is the major category of the system of national accounts characterizing the reproduction of vital activity of population. The share of this type of consumption in GDP remains steadily high, i.e., more than 50%. In real terms, final consumption expenditures of households in 2009 remained practically at the level of 2008 [18].

Need to denote, that nearly a decade before the crisis, BY's economy grew rapidly but its vulnerability to external shocks has also increased [19]. Such growth is best explained by consistently high rates of investment, made possible by large annual subsidies on energy imports and direct financial support from Russia as well as by educated and disciplined workforce [19].

Currently, growing external disequillibrium in the form of current account deficit clearly points out that a change in fundamental economic variables due to the transition process is required. It is associated with the fact, that currency of BY is overvaluated having in mind the worsened price competetiveness in the export sector [20]. Bearing in mind the lower level of development of BY's transition economy compared to the EU countries, faster economic growth is related with technological changes (energy sector among others [21]) and productivity improvements.

Table 1
Belarus primary energy supply and consumption by source in 2010.

Energy source	Energy supply
Production	
Oil, mln. t (Mtoe)	1.70 (1.70) [23]
Raw natural gas (associated gas), billion m^3 (Mtoe)	0.23 (0.20) [25]
Peat, mln. t (Mtoe)	2.20 (0.51) [24]
Firewood, mln. GJ (Mtoe)	65.72 (1.57) [26]
Electricity (including hydroenergy), billion kW h (Mtoe)	34.70 (2.97) [23]
	34.56 (2.96) [27]
Imported	
Oil, mln. t (Mtoe)	14.70 (14.70) [23]
Natural gas, billion m^3 (Mtoe)	21.60 (19.19) [23]
Coal, mln. t (Mtoe)	0.72 (0.48) [25]
Electricity, billion kW h (Mtoe)	3.00 (0.26) [23]
	2.90 (0.25) [27]
Consumption	
Oil, mln. t (Mtoe)	15.10 (15.10) [25,28]
Natural gas + associated gas, billion m^3 (Mtoe)	21.83 (19.40) [23,28]
Coal, mln. t (Mtoe)	0.72 (0.48) [25]
Firewood, mln. GJ (Mtoe)	65.72 (1.57) [26]
Electricity (including hydroenergy), billion kW h (Mtoe)	37.46 (3.22) [27]
Thermal energy, mln. Gcal (Mtoe)	73.2 (7.32) [25]

Note: The applied conversions from applied energy units to tonne of oil equivalent: 1 t of oil = 1 toe; 1000 m^3 of natural gas (or associated gas) = 0.888 toe; 1 t of coal = 0.666 toe; 1 t of peat = 0.2275 toe; 1 t of wood = 0.3215 toe; 1000 kW h = 0.086 toe; 1 Gcal = 0.1 toe.

2.3. Total primary energy supply (TPES) and existing energy system

BY belongs to the group of countries without large reserves of fossil fuel resources such as oil, coal and natural gas (NG) (see Table 1). During 2007–2010 period, net energy imports represented about 83–85% of BY total primary energy supply (TPES). Over 90% of electricity was generated from NG. The price of NG imported by BY from Russia in 2010 was about 3.5 times the equivalent 2006 value. The total installed power capacity of the BY energy system in 2010 consisted of about 8.247 GW, of which 42.7% are large condensing thermal power plants, 57.2% are CHP plants and 0.1% are small thermal power plants, hydropower stations and hydro power plants. District heating (DH) and combined heat and power (CHP) production were found to consume about 70% of the country's fuel needs. That finding triggered a systematic move from inefficient boiler plants into more efficient models and a shift to mini-CHP plants [22]. Energy use by the sector of an economy for BY is presented in Table 2.

The largest part of energy based on local fuel and energy resources is intended for generation of energy for heating. The most significant source of alternative energy in BY is firewood (see Table 1) accounting for approximately 85–90% of total RES consumption. Currently, more than 460 boiler plants are operating in the country using the combined combustion of firewood and other types of fuel, including combustible renewables.

In the nearest decade, the most perspective directions of RES development in BY are wind energy and biomass fuels. Gradually reducing firewood share to 48% (of total RES consumption), other alternative energy resources are going to be dramatically increased: wind power – by 700 times (from 0.02% to 14%); biodiesel – by 25 times (from 0.28% to 7%); biogas – by 25 times (from 0.2% to 5%); solar energy – by 8 times (from 0.25% to 2%); agricultural waste – by more than 5 times (from 3.7% to 20%) [30].

3. Assimilation of renewable energy sources in Belarus

3.1. Liquid biofuels for transportation

3.1.1. Biodiesel

In Belarus, the production and application of vehicular fuel from agricultural origin (biodiesel) have been put into practice

Table 2
Energy use by the sector of an economy for Belarus (year: 2007) [29].

Sectors of economy	Oil (Mtoe)	NG (Mtoe)	Petroleum products (Mtoe)	Coal and peat (Mtoe)	Combustible renewables (Mtoe)	Hydroenergy (Mtoe)	Electricity (Mtoe)	Thermal energy (Mtoe)
1 Energy sector:								
Electricity plants	0	3.753	0.015	0	0	0.003	0	0
CHP plants	0	5.909	0.056	0.019	0.051	0	0	0
Heat plants	0	2.969	0.300	0.108	0.452	0	0	0
Own use	0	0	0.513	0.013	0.022	0	0.322	0.358
Distribution losses	0.385	0.154	0.014	0.044	0	0	0.320	0.617
2 Industry sector	0	1.692	0.564	0.057	0.157	0	1.214	1.980
3 Transport sector	0	0.432	1.698	0.007	0	0	0.157	0
4 Other sectors								
Residential	0	1.199	1.214	0.231	0.580	0	0.517	2.230
Commercial and public services	0	0.003	0.004	0.002	0.155	0	0.297	1.127
Agriculture and forestry	0	0.040	0.760	0.003	0.037	0	0.123	0.157
Non-specified	0	0.016	0.062	0.058	0	0	0.160	0
Total:	0.385	16.167	5.200	0.552	1.454	0.003	3.110	6.469

only since the second half of 2007 (Fig. 1). OAO 'Grodno-Azot' was the very first company in BY, that developed and opened two biofuel production facilities of 5000 t/year capacity each.

Liquid biofuels produced sustainably do not harm society, the environment, or the economy, and may contribute to progress in each. On this understanding, the promotion of transportation biofuels was included in 'Sustainable Development Plan' [3] and 'National Programme' [4] as one of the most important condition. Several energy tax policy measures have already been instituted to encourage foreign investment in transportation biofuels sector, allowing to eliminate the disparities in prices (tariffs) for energy. To attract foreign direct investment and to realize the full potential of foreign investors (financial, manufacturing, and intellectual) it is considered to establish joint ventures, including outside the country, and foreign companies in the country [32,33].

Despite its small capacity, the vegetable oil methyl ester production sector is currently undergoing rapid development with the annual growth of ~8.7 times in 2008, ~3.6 times in 2009, and ~1.4 times in 2010 (see Fig. 1). BY's largest biodiesel producing companies are: the concern 'Belneftekhim', OAO 'Mogilevkhimvolokno', OAO 'Belshina', and OAO 'Grodno-Azot'. They encompass the complete biofuel's supply chain for Belarusian refining enterprise OAO 'Naftan' to produce diesel fuel (B5). In the last couple of years, B5 was available only at government-owned filling stations, though, since 01 April, 2010 it can be purchased at commercial filling stations as well [31]. In the year 2011, production started of a diesel fuel (B5) with ultra-low sulphur content ($>0001\%$ of mass) that complies with Euro-5 specification.

3.1.2. Bioethanol

Currently, bioethanol production in BY is still in its early stage of development (see Table 3). It is well known, that liquid biofuels produced from traditional food and feed crops are increasingly criticized worldwide for their adverse impacts on food security and GHG emissions, essentially because they can divert land from food and feed [5,33–41]. However, competition between food and crops in BY is not constrained by availability of agricultural land in terms of total extent of land that's unfit for growing crops for human consumption: over 23% of the country's land area was contamined with radioactivity released during the explosion at the Chernobyl Nuclear Power Plant on 26 April, 1986. Before the collapse of the Soviet Union, the Polesie State Radiation Ecological Reserve was established on most of that land. Twenty-five years later, over 50 thousand km^2 remain contaminated, with continuing adverse health, social, economic and cultural consequences [42,43]. As shown in Fig. 2, the Caesium (^{137}Cs) level in the undisturbed land remains the same in 2000 as it was observed immediately after the accident in 1986 [43]. Scientists estimate that the process of natural decay could take 300–600 years to rid the undisturbed soil of contamination. Despite the bleak forecast,

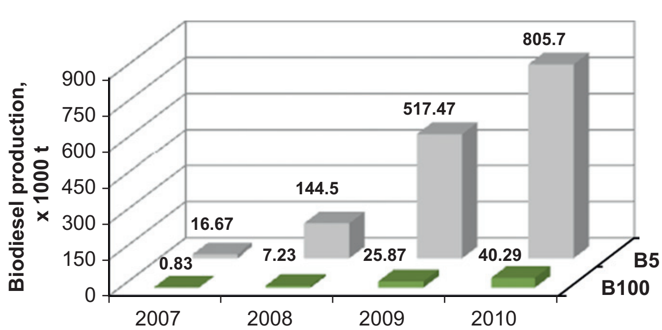

Fig. 1. Biodiesel production capcities in Belarus (a pruned nomenclature of fuel blend B5 means what percentage of biodiesel (vegetable oil methyl ester) is actually in the fuel, the rest is fossil diesel).

Table 3
Bioethanol production projects under development in Belarus (year: 2010).

Country	Plant	Scale	Feedstock	Status	Comments
Belarus/ Ireland	'Ethanol' Mozyr Integrated Plant (500 million litres per year);	600,000 t/year 1^{st}-generation bioethanol production plant planned with The Belarusian State Concern of Food Industry 'BELGOSPISCHEPROM' (6 Aranskaya str., 220006, Minsk).	Crops to be grown on radiation contaminated land near Chernobyl	In December 2007, signed a framework agreement on bioethanol production.	To be based on ethanol facilities operating in Belarus at Mozyr and Bobruisk.
	Babruysk Hydrolysis Plant (100 million litres per year).	Project budget: ● Greenfield Project Management Ltd.—345 million USD; ● Belarusian government—22.8 billion rubles.		Feasibility study, feedstock logistics study.	'Litasco' (LUKoil International Trading and Supply Company) intends to blend Greenfield's bioethanol with LUKoil's petrol to make E5, E10 and E85.
Belarus	OJSC 'Zhabinka Sugar plant	60,000 t/year bioethanol production plant planned with The Belarusian State Concern of Food Industry 'BELGOSPISCHEPROM' (6 Aranskaya str., 220006, Minsk).	Sugar production waste, sugar beet	By 2012 it is planned to develop an experimental technology of biofuel production for petrol engines based on bioethanol with the creation of the current sample of the target biofuel plant	Experimental-industrial factory at Zhabinka town.
		Project budget—75.4 (81.6) mln. USD: ● equipment—49.4 mln. USD; ● building works—18.1 mln. USD; ● design-budget documentation—2.1 mln. USD; ● risks—5.7 mln. USD.			By 2015 annual bioethanol production can reach 50–60 thousand tonnes.

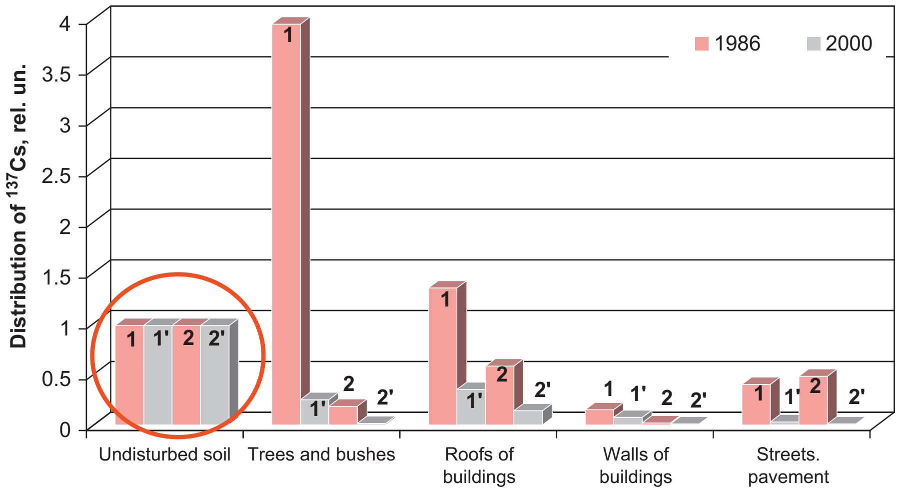

Fig. 2. Comparison of Caesium (^{137}Cs) distributions within the different mediums: 1, 1′—dry deposition; 2, 2′—wet deposition.

a concept of removing of the radioactive particles from the soil by repetitive harvests of grain and beet crops found a fairly widespread appeal among policymakers and other stakeholders in developing a more sustainable bioethanol (and biogas) production. There is a reason to believe that using these crops as feedstock in biofuel production and employing processes modified to handle the radiation involved, the development of bioethanol refineries at the 'Ethanol' Mozyr Integrated Plant and the Babruysk Hydrolysis Plant in the Mahilyov region (joint capacity: 650 million l/yr) [44] could cut this period to between 30 and 60 years. Bioethanol to be produced by the proposed refineries is seeing their own export markets in the EU (see Table 3).

For use in the local transportation sector, production of liquid hydrocarbons from sugar beet and sugar production wastes in OJSC 'Zhabinka Sugar Plant' is scheduled by 2012–2015 (Table 3). In the long term, bioethanol is likely to be produced from other biomass sources as well.

3.2. Biogas

Among the wide range of alternative energy sources in BY, utilization of the organic wastes in biogas systems is often viewed as one of the most promising solution having a direct impact on improving the rural standard of living. While use of biogas systems is not restricted to rural areas, the difficulties of retrofitting such systems in urban areas, supplying a balanced charge of biomass, generating adequate pipeline pressure, and minimizing capital costs all sugest that biogas systems will be more easily adapted, in the short term, to rural areas [45]. Anaerobic digestion benefits can significantly affect hygienic conditions, reduce air and water pollution, save mined fuels and firewood (protect forests), produce bio-organic fertilizer, etc.

The Republic disposes a large number of agricultural and food industrial enterprises, located in peripheral regions [15,23,24] with sufficient raw materials for biogas production (Table 4). According to the requirements of the different substrates for the production of biogas different technologies are used [46]. These technologies can be classified by the type of reactor (see Table 4) into wet fermentation reactor (up to ~15% dry matter content) and dry fermentation reactor (~25–50% dry matter content), by the type of feeding (continuous or batch reactor), by the process temperature (psychrophilic operation up to 20 °C; mesophilic operation 30–40 °C; thermophilic operation 55–60 °C) and by the number of stages (single-stage, two-stage, multi-stage operation) [45–52].

Table 4
Potential biogas and metahane (CH_4) yields of energy-rich substrates available in Belarus for anaerobic digestion.

Energy-rich substrates	Dry matter (DM) (%)	Organic dry matter (ODM) (%)	Biogas yields, m^3/t		CH_4 yields (%)
			Wet biomass	Dry biomass	
Cattle slurry	8–11	75–82	15–25	200–500	60
Pig slurry	7–8	75–86	15–25	300–700	60–70
Cattle manure	25	68–76	40–50	210–300	60
Pig manure	20–25	75–80	55–65	270–450	65
Poultry manure	32	63–80	70–90	250–450	65–75
Corn silage	20–35	85–95	170–200	450–700	50–55
Sewage sludge	5–24	80–95	35–280	900–1200	60–72
Animal fat	2–70	75–93	11–450	700	60–72
Slaughterhouse wastes	40–75	50–70	80–120	150–600	67
Catering wastes	9–37	80–98	50–480	200–500	45–61
Market wastes	5–20	80–90	45–110	400–600	60–65
Rye (green mass)	30–35	92–98	170–220	550–680	55
Sugar beets	23	90–95	170–180	800–860	53–54
Grated beets	12	75–85	75–100	620–850	53–54
Beet leaves	16	75–80	70	550–600	54–55
Grass silage	25–50	70–95	170–200	550–620	54–55
Green grass	12	83–92	150–200	550–680	55–65
Waste products of brewery	20–25	70–80	105–130	580–750	59–60
Distillers grains	6–8	83–88	30–50	430–700	58–65
Distillery effluents (potatoes)	6–7	85–95	36–42	400–700	58–65
Distillery effluents (fruits)	2–3	95	10–20	300–650	58–65
Oilcake	22–26	95	60–75	250–350	70–75
Molasses	80–90	85–90	290–340	360–490	70–75
Squeezed apples	25–45	85–90	145–150	660–680	65–70
Squeezed fruits	25–45	90–95	250–280	590–660	65–70
Squeezed root vegetables	40–50	80–90	250–270	640–690	65–70

Note: The availability of substrates types has been identified according to production profiles of state-owned enterprises [15,23,24]. The properties of energy-rich substrates, biogas and methane yields have been adapted from Ref. [46] and data available elsewhere in the scientific literature [47–52].

Independently of factors such as geographical location and season [51], farm livestock and poultry coverage has the widest range of options to further reduce greenhouse gas emissions

(methane and nitrous oxide) by substitution of fossil energy use and through changes in manure handling: in BY, there are over 6300 farms of different sizes intended for commercial livestock production and cattle fattening, over 100 pig-breeding farms, 48 poultry-breeding complexes and poultry farms [15,23,24]. As a result of their activity, a large amount of biomass is cumulated with annual output exceeding 20 million tonnes. Their biogas potential is about 2.5 billion m^3/yr [53].

Currently, there are three large farm-based biogas plants in the country with total capacity of 1.19 MW located at 'Zapadnyi Selekcionno-Gibridnyi Centr KSUP' in Brest region, 'Plempticezavod Belorusskiy KSUP' in Minsk region, and OAO 'Gomel'skaya Ptitsefabrika' in Gomel region. 39 biogas plants with a total capacity of 40.4 MW should be installed by 2012, with the goal of generating around 340 million kW h of electricity and reducing NG imports by over 0.102 Mtoe per year [53]. Ministry of Agriculture and Food, State Committee on Standardization, Ministry of Housing and Communal Services, National Academy of Sciences of Belarus, regional executive committees and Minsk City Executive Committee, 'Belgospischeprom' (The State Food Industry Concern of the Republic of Belarus), 'Belbiofarm' (The Belarusian State Concern on Production and Sales of Pharmaceutical and Microbiological Products) and 'Belneftekhim' (The Belarusian State Concern for Oil and Chemistry) are indentified as state customers and executives of the program [53].

3.3. Peat as a slowly renewing biomass fuel

Official frameworks for soil monitoring exist in most states of the EU [54]. Since 2002, The Soil Geographical Database of Europe covers BY as well [55]. Accordingly, with 14.2% (29687 km^2) of the territory BY has a remarkable amount of peatlands unique for Europe [55,56]. Around 9000 peatbogs with peat available in the energy equivalent of 1285.4 Mtoe were discovered in the second half of the 20th century [29,56–60]. At present only 70% of peat reserves are left. Main reserves are found on the areas occupied by agriculture or nature protected areas. Only 250 million tonnes (56.88 Mtoe) are considered for development and 100–130 million tonnes (22.75–29.76 Mtoe) as mineable reserves [56].

Projections of peat extraction and use for energy and agricultural purposes in BY for the period up to 2020 are formulated in the State Program 'Peat' [58]. Accordingly, there are 46 peat deposits under exploitation. Table 5 summarizes the distribution of peat reserves by regions of BY. The largest areas of peat formation (49.7% of the available reserves in currently active peat mining areas) are located in the marshy wetlands in the central part of BY (Minsk region).

Table 5
Distribution of peat reserves for energy and for agriculture in developing peat deposits in different regions of Belarus in 2007, Mtoe [29,58].

Distribution	Region						TOTAL
	Brest	Gomel	Grodno	Minsk	Mogilev	Vitebsk	
For energy	2.676	1.637	2.446	8.723	0.803	1.262	17.547
For agriculture	0.186	0	0.442	2.277	0.378	2.331	5.614

The main product of the peat industry are briquettes. In 2010, approximately 2.93 million tonnes (0.7 Mtoe) of briquettes were produced, from which 1.685 million tonnes (0.4 Mtoe) were exported [29,58]. Key importers are Sweden, Lithuania, Latvia, Poland and Germany. On the basis of [58], the consumption of fuel peat briquettes in BY should be increased by up to 1.442 million t/yr (0.605 Mtoe/yr) by 2020.

Among the all types of fuel peat produced in BY in 2010, pellets comprised only a very small part (0.47%), which is equal to 4000 t or 0.7 toe. Since 2008, pellet exports surpass half of the annual production [29,58]. State Program [58] foresees gradually increase in pellet production with the highest reaching up to 52,000 t/yr (12.6 toe/year) by 2020. Curently, a pilot project on the production of peat pellets (capacity: 12 t/yr) is under development by the largest producer of baled peat—OAO 'Zelenoborskoye'. In 2011–2014, the Vitebskoye Unitary Enterprise 'Beltopgaz State Production Amalgamation' plans to introduce peat pellet production line with a capacity of 40 t/yr by 2020 [29].

In 2010, the consumption of fuel peat in the country was 0.86 Mtoe (Table 6). In spite of considerable peat reserves, without refurbishment of existing boiler-houses or building of new ones designed to run on this kind of fuel, coupled with introduction of methods for recycling of worked-out deposits, drastic increase in peat consumption during the next decade is believed as unrealistic and its production is not expected to exceed 1.3 Mtoe/yr (see Table 6).

3.4. Wood biofuels

In the years since the end of the World War II, the area of BY covered by forest has been increased by 81% as compared to data available for 2010 (Fig. 3) [61]. This means that comparisons between the standing stock of natural wood resources and its rate of consumption for energy generation coupled with the creation of forecasts related to sustainable development of country's economy are highly important.

According to the complex botanical-geographical regionalization, the forest area in BY is divided into three subzones:

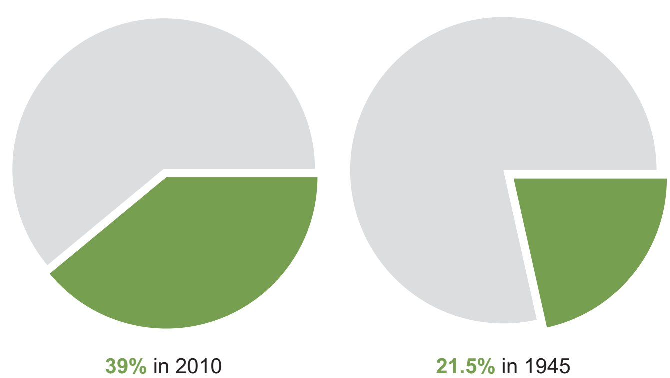

Fig. 3. Forest cover as percent of total land and water area of Belarus [61].

Table 6
Development of peat production in different regions of Belarus, Mtoe [58].

Year	Region						TOTAL
	Brest	Gomel	Grodno	Minsk	Mogilev	Vitebsk	
2010	0.167	0.103	0.146	0.305	0.055	0.085	0.860
2015	0.192 (+13.0%)	0.124 (+16.9%)	0.155 (+5.8%)	0.359 (+15.0%)	0.059 (+6.8%)	0.136 (+37.5%)	1.025 (+16.1%)
2020	0.196 (+2.0%)	0.129 (+3.9%)	0.197 (+21.3%)	0.388 (+7.5%)	0.062 (+4.8%)	0.194 (+29.9%)	1.167 (+12.2%)

European broad-leaved forests adjoining the forest-steppe zone and Eurasian mixed coniferous (taiga) forests [62]. Forests cover 39% (or ~81 thousand km^2) of the Republic's territory [23] thus being the predominant vegetation type and one of the major natural resources. Native flora of BY includes 28 tree species [62]; the most common widespread are following: pine (3.994 million ha), birch (1.919 million ha), spruce (0.747 million ha), black alder (0.680 million ha), oak (0.280 million ha) and aspen (0.168 million ha) [63]. In 2010, timber stock was 1.6 billion m^3 and it is projected that in 2030 it will reach 2.2 billion m^3 which will be an important carbon sink over the next 20 years.

Currently, proprietary rights to all forest areas belong to the state. The management of the dominant part (85%) of all forest areas is carried out by the Ministry of Forestry of The Republic of Belarus (hereinafter referred to as 'Minleshoz') [63,64].

The forecast of average annual biomass wood production that can be removed from harvesting sites by source and region in BY in 2010–2015 is shown in Table 7.

The total potential operationally available woodfuel in Belarus during the present forecast period of 2010–2015 is 12.9 million m^3 [64]. The predominant source of fuel wood in BY are logs from sceduled harvesting (85% of the total energy wood). On the basis of literature data on forest sector in BY [29,63,64,66], the Vitebsk and Gomel regions have the highest potential of wood-for-fuel, i.e., 3.3 million m^3/yr and 2.3 million m^3/yr, respectively. Actual woodfuel consumption both for energy production and technological needs is estimated at 8.2 million m^3 per annum. Regarding forest industry by-products, it is assumed that 75% of the felled roundwood is turned into final products. The remaining 25% consists of by-products (bark, sawdust and wood chips) available for energy purposes [65]. The projected balance of fuel wood resources is 4.7 million m^3 [29,64], which potentially makes it possible to use for the newly established industrial heat-only boilers (HOBs), power plants, briquettes production, etc [66].

With a view to upgrading and increasing fuel wood production and delivery issues on a local level (see Table 8), the Resolution of the Working Board of the Ministry of Forestry of the Republic of Belarus [67] has been approved in 2010. The basic precondition for the economic success of the fuel wood production systems to be installed until 2015 naturally is the existence of a local fuel wood market [68] with constantly growing demand on firewood, woodchips, wood briquettes, and pellets. Respective local institutions under the authority of the government set fuel wood production targets for all related suppliers, including companies involved in the forestry business and forest management. The data presented in Table 8 refer to markable incraese in total production volumes of fuel wood (3–10 times, depending on fuel type) and approximately two-fold increase (1.80–2.44 times) in production volumes over the next several years until 2015.

3.5. Woodfuel-specific crops

Growing wood fuel-specific crops by short rotation coppice SRC (in 3–5 year cutting cycles) or short rotation forestry SRF (in 10–25 year crop duration) [69] can serve several purposes in addition to the production of woodchips. They can at the same time act as a absorbent vegetation filter to process radioactive Caesium in soil.

SRC and SRF have not been widely planted in EU states since they require high quality arable land for good yields but produce a lower quality crop. In the case of BY, willow SRC has many advantages for contamination scenarios distinctive to Polesie State Radiation Ecological Reserve (PSRER) and can grow on a wide variety of soils. Through a literature review on opportunities of SRC-for-energy in PSRER [69–73], there were identified, that harvest is recommended exclusively in winter when growth has finished and the leaves have fallen, farm labour is available and when a snow cover may partially shield the labourers against radiation. Soil is not cultivated throughout the rotation thereby limiting secondary contamination. Crop management is not labour intensive, so it has favorable advantages in contamination conditions [69]. Generally, willow plantations were assumed to be grown on peaty soils able to produce yields in excess of 6 t/ha. Since most soils in PSRER are of a sandy nature, smaller yields can significantly increase the value of the woodchips. This may affect transport distance and availability of product, affecting both profitability of production and conversion [69].

So far several research projects on woodfuel-specific crops were performed in BY. The first one was carried out by the Institute of Power, which studied opportunities of willow SRC cultivation on lands contaminated with radio-nuclides, and was finished in 2005. Among the many research targets, the study resulted in the economic assessment of technology application for the willow SRCs. Another project was delegated by the Ministry of Energy to its consolidated group 'Beltopgaz' in 2005 [13]. It was performed by the research institute RUP 'BelNIItopproject' in cooperation with the International Sakharov Environmental University (ISEU) [13,74]. Some of the results reported by the research institute explain that post-mining soils were poor quality lands, however, willows grow on them, though, with low yields [13,65].

Currently, only 324 ha of land in BY (the initial plan had been 200 ha) were sown with fastgrowing species of wood and bushes in order to promote the use of fuel wood. The distribution of SRC plantations by regions is presented in Fig. 4.

Table 7
Forecast of fuel wood harvesting in Belarus for 2010–2015, million m^3/yr [29,64].

Fuel wood source	Belarus	Region					
		Brest	Vitebsk	Gomel	Grodno	Minsk	Mogilev
1. Total energy logs from scheduled harvesting, including	**7.8**	1.0	1.7	1.6	0.8	1.6	1.1
Final fellings	**2.5**	0.3	0.7	0.6	0.2	0.4	0.3
Thinnings	**3.6**	0.5	0.7	0.7	0.4	0.7	0.6
Other fellings	**1.7**	0.2	0.3	0.3	0.2	0.5	0.2
2. Wood processing by-products	**2.0**	0.3	0.3	0.3	0.2	0.5	0.4
3. Grey alder plantations	**1.0**	–	0.8	–	0.1	0.1	–
4. Overmature deciduous tree species forests	**1.0**	0.1	0.3	0.2	–	0.1	0.3
5. Wood harvesting by-products	**0.5**	0.05	0.1	0.1	0.05	0.1	0.1
6. Dead-felled and dead-standing trees (50%)	**0.6**	0.1	0.1	0.1	0.1	0.1	0.1
Total fuel wood potentials	**12.9**	1.55	3.3	2.3	1.25	2.5	2.0
Use of fuel wood by energy plants, mills, private households	**8.2**	1.0	1.6	1.6	0.8	1.9	1.3
Balance of fuel wood potentials for development	**4.7**	0.55	1.7	0.7	0.45	0.6	0.7

Table 8
Installation of new production capacities of fuel wood in Belarus [67].

No	Region and type of fuel wood	Installation of new production capacities/ (total production volumes by 'Minleshoz' companies)						Total
		2010	2011	2012	2013	2014	2015	
Wood pellets, thousand t		7.5 (6.0)	6.0 (9.0)	0.0 (13.0)	0.0 (16.0)	0.0 (19.0)	0.0 (19.0)	**13.5 (19.0)**
1	Vitebsk	7.5						7.5
2	Grodno		3.0					3.0
3	Mogilev		3.0					3.0
Wood briquettes, thousand t		4.5 (0.0)	1.5 (2.0)	1.0 (4.0)	1.0 (6.0)	1.0 (8.0)	2.0 (9.0)	**11.0 (9.0)**
1	Vitebsk		1.5					1.5
2	Gomel	1.0				1.0	2.0	4.0
3	Grodno	2.0						2.0
4	Minsk				1.0			1.0
5	Mogilev	1.5		1.0				2.5
Firewood, thousand m^3		16.2 (3.0)	4.5 (15.0)	2.0 (17.0)	4.5 (22.0)	4.0 (26.0)	4.0 (30.0)	**35.2 (30.0)**
1	Brest	3.0						3.0
2	Vitebsk					2.0		2.0
3	Gomel	13.2						13.2
4	Grodno		2.5		2.5			5.0
5	Minsk		2.0	2.0	2.0	2.0	4.0	12.0
Woodchips, thousand m^3		294.0 (300.0)	80.0 (500.0)	93.0 (600.0)	22.0 (700.0)	43.0 (800.0)	20.0 (900.0)	**552.0 (900.0)**
1	Brest	20.0			2.0	3.0		25.0
2	Vitebsk	60.0	20.0	20.0	10.0			110.0
3	Gomel	131.0						131.0
4	Grodno	43.0	20.0	3.0				66.0
5	Minsk	20.0	20.0	50.0	10.0	40.0	20.0	160.0
6	Mogilev	20.0	20.0	20.0				60.0

As seen in Fig. 4, the largest SRC plantation with the planted area close to 1.5 km^2 is located in Minsk region, while other ones do not exceed 0.5 km^2. Nevertheless, according to information from INFORSE Vision 2050 [25], it is expected that the development of energy plantations should start to take off after 2020 and that the area then will be increased with 10 thousand ha anually until 2040. An earlier study [75] also revealed that land suitable for woodfuel-specific crops production (miscanthus, willow and poplar species) in BY accounts for 305 GJ per capita. It is the largest share among the Former Soviet Union countries including Russia and Ukraine [75].

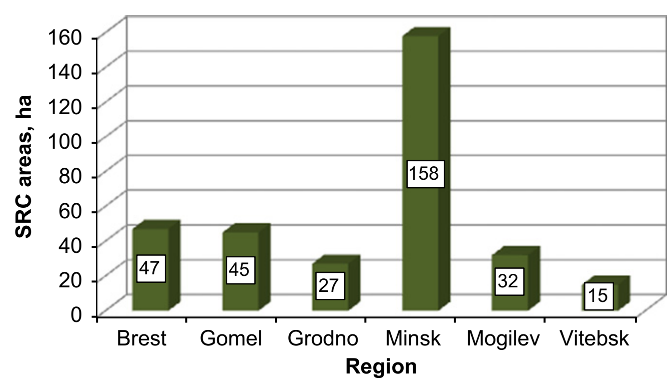

Fig. 4. Distribution of SRC plantations by regions of Belarus [43].

3.6. Straw biomass

Primary agricultural residues (e.g., straw, stalks) in BY are most commonly used as organic fertilizer instead to provide the process energy for the processing plants. Therefore, the economic potential for biomass straw is certainly much smaller than the technical potential. However, other materials with their appropriate actions on the crops can easily substitute straw in its current uses. For example, most waste straw now produced is left behind on the fields [11,76], notwithstanding the fact that application of chemical fertilizers allows the same production of crop yields. The plowing of waste straw supplies organic compounds that facilitate the activity of many microorganisms living in a zone of intense biological activity. On the other hand, this practice can only harm a crop when the waste straw is plowed into a field just before planting crops, as the decomposition produces organic compound with acidic properties [76]. Though some people assert that the supply of non-degradable inorganic fertilizer alone deteriorates soil conditions after long periods, there is a lack of consensus about the frequency of plowing and the amounts of organic fertilizers that need to be plowed in order to maintain good soil characteristics [76]. In addition, more has to be learned about the effectiveness of other inorganic compounds needed by the food crops for enhanced and nourished growth [76].

To solve part of this problem, Golub [77], propose to use a variable value for $C_{\%}$, adjusted to the experimental data according to a fitting law of the type $C_{\%} = -0.57\ D + 48.66$, where $C_{\%}$ is the maximum possible amount of straw available for heating requirements as a percentage of the total amount of crop straw production, %; D is the annual demand for humus, kg/ha.

In accordance with the balance of primary agricultural residues use in the Belarusian agro-industrial enterprises during 2009, straw yields of different grain and leguminous crops totaled at 8 million tonnes; free straw resources amounted to 957.1 thousand tonnes [78]. However, only a very small part of the surplus straw is used in an effective way.

The first and only fully automatic operated straw-fired boiler house based on straw combustion in a grate furnace put in operation within BY is situated in the town Glusk (at Unitary municipal enterprise UKP 'Zhilkomhoz'), Mogilev region. The 2 MW boiler unit, type 'CH COMPACT' was made and supplied by Belarusian-Frech company COOO 'Komkont' under the license of Group 'COMPTE.R.' (the leading manufacturer of wood-fired boilers in France) in 2010. The plant's annual straw consumption is approx. 2.8 thousand tonnes. In a given case, the newly-built boiler house leads to the annual fuel economy equal to or more than 0.475 ktoe.

In the short term, it is expected to have a bigger effect on using energy saving installations (straw-fired stoves) for reequipping an outdated grain dryers [78] of the type M-819. Currently, there are 5111 wet grain drying units under active exploitation country-wide.

The majority of these installations can be grouped in two broad categories: drying complexes (~3.5 thousand pcs.) and free-standing dryers (~1.5 thousand pcs.). To this day it is estimated that about 45% of all grain dryers (more than 2 thousand pcs.) of small- and medium-sized capacity (up to 40 t) have been retrofitted to fire local biomass, for the most part peat. The remaining 55%, or approx. 3 thousand pcs. are still running on natural gas.

Examples of adoption of in-store drying in conjunction with straw-fired dryers were relatively little spread in BY until 2007. Since then, slowly but surely, the spread of grain drying technologies based on straw-firing systems has gained momentum and funds are starting to flow for retrofit projects: during the three-year period 2007–2009, NG and liquid propane fuelled dryers in 17 agricultural enterprises of the Mogilev region have been converted to operate on straw [79]. In some areas of the Gomel region, 20 straw-fired energy saving stoves for reequipping grain dryers M-819 have been installed practically at the same time [80].

In BY, a clear incentive to produce mixed biomass (straw) pellets and briquettes is the available surplus of crop straw as cheap raw material. Straw pellets are a novice on the pellet market, as national quality standards for them do not exist. Some wood pellet producers switch to straw pellets production from time to time, but the production quantities do not exceed 800–1200 t per year [80]. An exeption could be the Kletsk branch of the state-run enterprise 'Minobltoplivo' located in Minsk region disposing the straw pellet production line built in 2011 with the capacity of 2 t per hour [81]. Summing up, the market is developing and unstable [82]. The interest from the manufacturer's side is increasing due to legal incentives, aiming at popularisation of RES and biomass use [82]. The demand for this kind of fuel made of renewable resources straw is expected to rise in BY.

3.7. Solar energy

Costs for the electricity generated in existing gas and coal-fired power plants of BY are constantly rising. This is a real driver for the full competitiveness of photovoltaic (PV) technologies. However, the solar energy for a direct electricity generation has no industrial significance in the country at the moment.

In the Eastern part of Europe, BY is located in between 53° 00′ North latitude and 23° 00' East longitude which determines the angle of incidence of sunlight (47° at noon time), length of a day (>10 h) and sunshine, and causes relatively large amounts of solar energy being available: from 3500 MJ/m^2/yr (0.972 MW h/m^2/yr) in the Northern areas to 4050 MJ/m^2/yr (1.125 MW h/m^2/yr) in the Southern areas, respectively. The average number of clear days each year varies from 30–35 (N-W) to 40–42 (S-E) as well as cloudy days vary from 175 (N-W) to 135 (S-E), respectively. The average solar duration is 1730 h/yr in the N-W and 1950 h/yr in the S-E.

Actually, the location of BY, its meteorological conditions, latitude and altitude are not limiting factors for the current and future development of PV. As described in [25], the potential of solar hot water could contribute between 1.25 and 1.75 Mtoe/yr and of solar power 1.0–1.25 Mtoe/yr. It is estimated that today more than 40% of all building roofs and 15% of all building exterior sides are suited for PV applications [83]. Provisional figures show a total prospective installed capacity comprising 8 m^2 of solar collector (3 m^2 for heat and 5 m^2 for electricity) per person of BY by the end of 2020 [25]. Currently, only several experimental PV installations exist in BY.

Though, as shown in Table 9 below, technological innovations combined with manufacturing optimisations will radically reduce the cost per unit during next decade [83], to make PV technologies more attractive for industrial applications, especially in Eastern European countries. Resultantly, the feed-in of intermittent electricity supply later from photovoltaic can be managed with regulation on thermal and power plants coupled with the construction of new heat storages (see Table 9) in the form of hot water tanks to the CHP plants to disunite heat production and heat demand [25]. Scientists and entrepreneures from pilot production of solar modules have no doubts that produce electricity from the sun it is quite appropriate in BY. The study found that Germany (the light level is lower than in Belarus), which by end 2010 had more than 16 GW of photovoltaic electricity integrated into its network, is still a long way from exceeding grid limitations. However, taking into account current electricity price levels for the different groups of end consumer, foreign and local investors do not consider BY an attractive place to build an industrial and utility-scale PV power plants before the 2020–2025 timeframe.

3.8. Hydroelectric energy

BY is endowed with abundant water resources distributed in many parts of the Republic: 470 lakes (145 man-made lakes among them) with the area exceeding 50 ha together with average river runoff evaluated at 57.9 km^3/yr, of which 34 km^3 are formed within the country [84,85]. Rivers of the Black Sea and the Baltic Sea drainage basins account, respectively for about 55% and 45% of annual water discharge. In the case of intense rainfall throughout the year, the total water flow of rivers increases to 92.4 km^3 and in poor rainy years it decreases to 37.2 km^3 [84].

The installed power capacity of 30 hydropower (HP) plants (Table 10) in BY is 12.12 MW [86].

Based upon the data calculated in 1960, the gross theoretical HP potential of BY is roughly 7500 GW h or 0.645 Mtoe per year and the technical potential is 2500–3000 GW h or 0.215–0.258 Mtoe per year. In 1967, the economic potential has been carried out only for 3 HP stations, which at that time comprised 900 GW h or 0.08 Mtoe per year [87].

Table 9
Ten-year objectives for photovoltaic technologies development in the world [83].

Global evolution of PV electricity technologies for commercial applications		2007	2010	2015	2020
Turnkey price large systems (EUR/W)		5.0	2.5–3.5	2.0	1.5
PV electricity generation cost (EUR/kW h)		0.30–0.60	0.14–0.20	0.10–0.17	0.07–0.12
Typical PV module efficiency range (%)	Crystalline silicon	13–18%	15–19%	16–21%	18–23%
	Thin films	5–11%	6–12%	8–14%	10–16%
	Concentrators	20%	20–25%	25–30%	30–35%
Inverter lifetime (yr)		10	15	20	>25
Module lifetime (yr)		20–25	25–30	30–35	35–40
Energy payback time (yr)		2–3	1–2	1	0.5
PV+small-scale storage (EUR/kW h)		–	0.35	0.22	<0.15

Table 10
Hydro-electric power stations in Belarus.

Hydro-electro-station	Installed capacity (MW)	Annual production (GW h)	Year the last block was released	Water resources for electric power generation
Vikhranskaya	0.250	Undisclosed	1926	Vikhra river
Lyakhazvinskaya	0.100	Undisclosed	1934	Lyahazva river
Papernya	0.200	Undisclosed	1946	Zel'vyanka river
Volpyanskaya	0.500	Undisclosed	1950	Ros' river
Gezgal'skaya	0.620	5.00	1950	Molchad' river
Novosyolki	0.200	Undisclosed	1950	Molchad' river
Selyavskaya	0.110	0.02	1953	Selyava lake
Zhemyslavskaya	0.200	Undisclosed	1953	Gav'ya river
Osipovichskaya	2.175	10.00	1953	Svislach river
Yanavskaya	0.160	Undisclosed	1954	Losha river
Braslavskaya	0.300	Undisclosed	1954	Druyka river,
Teterinskaya	0.370	1.17	1955	Druy' river,
Lepel'skaya	0.320	2.00	1958	Lepel'skoe lake
Chigirinskaya	1.500	Undisclosed	1959	Chigirinskoe dam lake
Rachunskaya	0.200	1.50	1959	Rachunskoe dam lake
Gonoles	0.300	Undisclosed	1994	Zaslavskoe dam lake
Lukomskaya	0.300	Undisclosed	2000	Lukomskoe lake
Vileyskaya	2.000	Undisclosed	2002	Vileyskoe dam lake
Dubrovskaya	0.150	1.00	2002	Usyazha river
Nemnovskaya	0.250	1.20	2003	Avgustovskiy canal
Zel'venskaya	0.150	0.50	2006	Zel'va dam lake
Soligorskaya	0.150	1.00	2007	Sluch' river
Minichskaya	0.200	2.50	2007	Minichi dam lake
Minskoy TEC	0.260	3.00	2007	Minskaya TEC-2
Duboy	0.330	1.40	2008	Dnepr-Bug canal
Sakovshchinskaya	0.225	0.99	2008	Berezina river
Ol'khovskaya	0.210	0.99	2008	Stracha river
Voykovskaya	0.100	0.41	2008	Dvinosa river
Zhodinskaya	0.030	0.18	2009	Plisa river
Chizhovka	0.260	1.70	2010	Chizhovskoe dam lake

Table 11
Ecologo-economic aspects of the potential hydroelectric power stations in Belarus [84–86,89–91].

River	Distance from river mouth, km	Net head, m	Hydro power (MW)	Area of the water in a reservoir (km^2)	Deep-water to shallow-water ratio of the aquatory
Tributaries of the Neman (Nemunas) river basin					
Neman (Nemunas)	598.0	6.4	15.18	55.3	2.82
Viliya (Neris)	234.6	9.6	11.6	9.3	1.84
	279.2	9.7	8.89	11.0	1.93
	347.1	7.0	4.77	18.2	2.12
Strana	29.8	7.0	0.42	0.3	4.0
	42.6	12.1	0.35	1.3	1.5
Shchara	57.0	6.0	2.20	27.0	1.0
Tributaries of the Western Dvina river basin					
Druyka	6.4	14.5	1.73	2.8	1.8
Vyata	1.1	23.5	0.92	2.0	5.67
Sar'yanka	6.6	8.0	0.67	1.0	1.0
	17.3	14.2	1.0	6.2	3.13
Drissa	53.8	7.6	3.27	6.6	1.64
	86.5	6.6	1.63	1.1	1.75
Svol'na	49.3	7.6	0.9	6.2	1.3
Nishcha	0.6	10.2	1.27	3.0	1.73
Diena	8.5	9.7	7.75	8.4	1.47
Mnyuta	2.4	10.5	0.74	3.4	2.4
	36.5	5.0	0.25	0.3	2.0
Berezovka	1.9	10.0	0.55	3.0	1.0
Zarezhanka	28.0	10.0	0.29	2.0	1.26
Ushacha	1.0	12.1	1.0	1.7	2.4
Obol'	12.3	12.6	2.24	5.9	2.28
Turovlyanka	2.2	5.0	0.43	0.2	1.0
Ulla	9.4	9.7	2.97	9.3	1.27
Usveyka	22.2	7.5	0.26	2.0	1.5
	45.0	11.8	0.33	1.6	1.67
Lukomka	13.1	9.6	0.63	1.4	1.33
Krivinka	8.5	6.7	0.24	0.8	1.33
Luchesa	15.8	10.6	2.47	22.0	2.28
Tributaries of the Dnieper river basin					
Dnieper	1310.0	7.6	24.41	366.3	1.5
	1410.0	5.6	9.21	115.3	1.2
	1671.3	4.7	5.52	5.3	1.41
	1715.0	4.7	4.92	4.1	2.42
Berezina	227.8	6.0	5.03	74.8	1.28

With the rapid development of RE sector, the number of including factors makes economical calculations necessary to have a tool like the potential to obtain the reliable economic analysis [88]. The central element of economic potential analysis [87] is a comparison of the discounted expenses of power generation at the HP plant (E_h) with the discounted expenses of obtaining power from other (thermal) station (E_{th}). The precondition, under which the societal net benefits of generating power from the HP plant rather than from another source has been expressed as $E_h = E_{th}$. In 2001, the new formula based on modern methods to calculate country's economical HP potential has been applied by Belarusian scientists [87] for the first time:

$$E_{th} = \sum_{t=1}^{T}[(c+e)N = gpP](1+r)^{-t} \Big/ \left(\sum_{t=1}^{T} P(1+r)^{-t}\right),$$

where T-calculated time period; t-year within a selected period; c, e-specific investments and specific annual operational expenses for other (thermal) power station; N-installed capacity; g-fuel consumption per 1 kW h of electricity produced; p-NG price forecast (for the t tax year); P-electricity generation (in the year t); r-discount rate.

According to the data calculated under the new scheme, the economic HP potential of BY at present is 0.325 GW or 1300 GW h/yr (0.112 Mtoe/yr) [87].

It is now estimated that BY's highest HE potential is in the river basins of the Neman, Western Dvina and Dnieper rivers of Grodno, Vitebsk and Mogilev regions (see Table 11). Based on this, Belarus, the Russian Federation and Ukraine have been working for several years on a UNDP/GEF Dnieper Basin Environmental Program Project, and have been discussing their desire to create a legal basis for a river basin management regime on the Dnieper River [92]. The countries have agreed to develop a Convention for the rational use of natural resources [92–94].

As of 2011, the development & construction of two large-scale hydroelectric power plants (HPP) are in progress. The first plant, namely Grodno HPP (17 MW), is located at Neman river and will be fully completed by 2012; the second one, namely Polotsk HPP (22 MW) is located at Western Dvina river and will be fully completed in four years until late 2015. Other regionally significant projects for hydro capacity growth in the 2012–2015 include:

- 4 large HP plants with a total installed capacity of 99 MW (the annual electricity generation is estimated to be around 450 thousand GW h) [95];
- 9 small and mini HP plants with a total installed capacity of 2.34 MW (8.7 thousand GW h/yr) [95];
- 20 micro HP plants with a total installed capacity of 0.75 MW (3.8 thousand GW h/yr) [95].

In the less predictable four-year period 2016–2019, an expectation is expressed regarding plans to set up six new HPP with a nominal generating capacity of 70.3 MW: 'Beshenkovichskaya'

HPP (30 MW; 2016), 'Orshanskaya' HPP (5.7 MW; 2017), 'Rechitskaya' HPP (4.6 MW; 2018), 'Verkhnedvinskaya' HPP (20 MW; 2018), 'Shklovskaya' (4.9 MW; 2018), and 'Mogilevskaya' HPP (2.1 MW; 2019) [95].

Since their commissioning, annual output of electric power generated within HP sector will reach approximately 860 thousand GW h in 2020 [95].

3.9. Wind energy

The commercial value of an onshore projects is highly dependent of the energy production, which in turn directly depends on the wind speed [96]. Since the energy that the wind generates is a cubic function of its speed, so every time the average wind speed doubles, the power output increases by a factor of eight [96,97]. Accordingly, small differences in average winds from site to site in BY mean large differences in production and, therefore, in cost.

Currently, the territory of BY has been divided into four wind zones [98]: I—less than 3.5 m/s; II—3.5–4.0 m/s; III—4.0–4.5 m/s; IV—more than 4.5 m/s (Table 12). The potential of wind energy is estimated to equal 1.9–2.0 Mtoe per year [1]. The technical potential of wind energy is estimated at 288.18 million MW h or 24.78 Mtoe [98] (Table 12). According to the the energy strategy of the Republic of Belarus through 2020, 1840 sites have been identified in the country. Their theoretical possible energy capacity is more than 1.6 GW.

In 2010, the total installed capacity of wind power plants amounted to only 2 MW, including wind farm 'Drushnaja' (0.25 MW+0.6 MW) and 'Minsk' (1.08 MW), plus several more small and insignificant installations. In the first half of 2011, the biggest in the country wind-driven generator type HEAG HW82/1500 with the capacity of 1.5 MW has been installed in the village of Grabniki, Grodno region. It is located 320 m above the level of the sea; the height of the tower is 81 m. The generator is expected to produce about 3.8 thousand MW h of electricity per year.

Energy generating companies in collaboration with State institutes attempt to construct some new types wind energy aggregates, one of which, lighter-than-air high altitude wind turbine, grounded on Magnus effect to keep a stable and controlled position in air [99]. There are already plans to build a 160 MW wind farm in Minsk reginion, Dzerzhinsk district during the 2011–2014 period. Besides, a wind park with a total capacity of 0.3 GW is planned to be built until 2015, states the Energy Policy of the Republic of Belarus for the period up to the year 2020.

The conversion to clean, sustainable and efficient generation of RE on the lines of the nature not inflicting damage to the climate has been initiated throughout the world and is vital nowadays, including BY [16]. However, in this field BY has been lagging behind as compared to advanced countries. Application of the energy stored in the atmospheric circulation is the cleanest of all the renewable commercial methods of generating electricity (Table 13) [100]. The precise savings in gaseous emissions will depend on the mix of generating plant in the power system to which the wind farm is connected. Any emissions caused during the manufacture of wind turbine plant are offset after a few

Table 13
Juxtaposition of ecological parameters of wind turbine and various RE-generating technologies [100].

Technologies for renewable energy generation	CO_2 (kg/GW h)	NO_2 (kg/GW h)	SO_2 (kg/GW h)
Wind turbine			
4.5 m/s	19–34	26–43	18–32
5.5 m/s	13–22	18–27	13–20
6.5 m/s	10–17	14–22	10–16
Hydro (large)	7–8	34–40	18–21
Hydro (small and micro)	10–20	46–86	24–46
Photovoltaic (all technologies average)	170–260	160–340	135–330

Table 12
Technical potential of wind energy in Belarus [98].

Region	Area of the region, thousand km^2	Zone number	Area of the zone (km^2)	Electricity generation	
				Per 1 km^2, MW h	Maximum per zone, million MW h
Brest	15.0	II	10.9	2.161	23.51
		III	3.1	3.840	11.74
		IV	0.9	6.534	6.11
				Region's total:	41.36
Gomel	14.1	II	1.4	2.161	3.02
		III	8.5	3.840	32.43
		IV	2.5	6.534	16.3
				Region's total:	51.75
Grodno	12.4	II	6.0	2.161	12.33
		III	2.9	3.840	11.09
		IV	2.3	6.534	15.22
				Region's total:	39.24
Minsk	16.8	II	9.9	2.566	25.42
		III	1.3	3.840	4.84
		IV	2.7	7.285	19.93
				Region's total:	50.19
Mogilev	12.6	II	10.5	2.161	22.74
		III	1.9	3.840	7.25
				Region's total:	29.99
Vitebsk	17.6	II	1.0	2.566	2.41
		III	4.2	4.962	20.11
		IV	7.3	7.285	53.13
				Region's total:	75.65
BELARUS	88.5	II	39.7	–	89.43
		III	29.2	–	87.40
		IV	19.6	–	111.35
				Total (BY):	288.18

months of emission-free operation [100]. Considering the above mentioned, BY is putting forward an ambitious tasks of reaching wind energy production and demand growth gain a momentum in many ways across the country in the nearest future.

4. Development and functioning of the fuel and energy complex

Energy sector of BY is a key life supporting system and the basic element which guarantees the integrity and efficiency for all industries and objects of the economy. It influences greatly on production costs, incomes of a society, and its material prosperity. The energy potential of the economy and its efficiency in the modern world are important indicators of the level of state development.

For the countries with deficits of their own energy resources, such as BY, optimal development and functioning of the fuel and energy complex is one of the priorities of legislative and executive authorities for all producers and consumers of fuel and energy resources directed to ensure competitiveness on the global market.

4.1. Investment support

Development of the RE sector jointly with country's energy potential as a whole requires significant capital investment. Total funding for 2011–2020 years will reach at least 45.5 billion U.S. dollars [78] (Table 14).

The most important instrument for implementing the strategy remains the development and implementation of state programs. The programs will be funded using the state support, private and public-private partnership, including through foreign borrowing funds from international financial organizations and national banking structures [78].

4.2. Directions of price and tariff policy

Power tariffs should take into account the economic interests of energy producers and consumers and provide incentives for maximum energy efficiency at all stages of production and consumption, and to improve the effectiveness of industrial capacity use. Currently, an improvement of tariff policy is carried out by using [78]:

- Staged optimization of energy tariffs, including establishing electrical energy tariffs differentiated according to the network connection points of the consumer with the subsequent formation of their stress levels, transition to payments for electrical energy on tariffs differentiated by day zones, to technically and economically reasonable tariffs differentiation depending on the technical parameters of the carrier, formation of the optimum ratio between two-part tariff rates for electricity and between these rates and the rates of one-part tariff;
- Creation of economic incentives providing use of energy-saving technologies in production processes;
- Creation of incentives for energy savings by the consumers;
- Formation and establishment of tariffs for electric energy according to activity (tariffs for generation, transmission, distribution and sale of energy);
- Staged elimination of cross-subsidies in energy resources tariffs by 2014, including tariffs for the population based on Strategy of Housing work for the period of 2011–2015 providing transition of these organizations to self-sufficiency.

Tariffs for the electricity produced from renewable energy sources currently are established at the level of electricity tariffs for industrial and similar consumers with connection load up to 750 kV A using raising factors differentiated according to the type of renewable energy (solar, wind, natural movement of water flows, fuel wood, other kinds of biomass, biogas and other) [78].

4.3. Strategy for improvement of the power industry control

One of the main objectives of the Strategy [78] in BY is improving the management of the power industry. In order to align the management structure and management in compliance with the conditions of market economy, to improve production efficiency and financial sustainability of the industry enterprises, to create conditions for attracting foreign investments a reform of the Belarusian power system is being planned [78].

An important objective of the reform in the Belarusian power system is to create a national wholesale electric energy (power) market [78]. Reform is planned to be carried out in three stages during the 2010–2015 period:

1) Stage I (2010–2011). Main tasks [78]:
   - Establishment of the Republican Unitary Enterprise (RUE) 'High-voltage electrical network' and the development of the regulatory framework of the Belarusian power system functioning in the new economic conditions.
2) Stage II (2012–2013). Main tasks [78]:
   - Establishment of the RUE 'Belgeneratsiya' to manage the largest power plants;
   - Preparation of conditions for power stations corporatization;
   - Expansion of functions performed by the regulatory authority (Ministry of Economy of BY).
3) Stage III (2014–2015). Main tasks [78]:
   - Completion of the reforming process of the Belarusian power system, creation of a wholesale electric energy market and favorable conditions for effective investment;
   - Establishment of wholesale electricity market, where RUE 'Belgeneratsiya' jointly with independent electricity producers

Table 14
Expected investment[a] of capital (million U.S. dollars) in Belarusian energy sector for the period of 2011–2015 and till 2020 [78].

Direction	2011–2015	2016–2020	2011–2020
1. Energy saving technologies and local fuel and energy resources, including biomass and RES	8663	8300	16963
2. Modernization of the energy system, including:	8500–9000	9500–10000	18000–19000
Fuel wood production	112	33	145
Peat industry	312	334	646
Gas transportation system	613	700	1313
Oil production	600	600	1200
Oil processing	2500	500	3000
Development of mineral raw material base	2000	2200	4200
Total:	23300–23800	22167–22667	45467–46467

[a] Construction of nuclear power plant and its credit repayment, therefore, were not included in the subgroup analyses.

will be the Suggesting party, and consumers who buy electricity for their own needs and for sale to other consumers will be the Demanding party;
- Establishment of power market operator coordinating all energy purchases and sales in accordance with market rules;
- Establishment of tariffs depending on the type of activity.

5. Conclusions

The review on the renewable energy sector in Belarus so far has tried to give the background for RES, to describe their occurrence and conditions for using them, leading up to a discussion of the role of renewable energy in current and future energy systems, depending on a path of economic transition, social values, availability, and the economic rules used to judge the viability of competing solutions. In order to assess future prospects of renewable energy use, it is essential to have thorough knowledge of the status quo, recent developments and unused primary energy potentials.

BY's geographic location has several advantages for extensive use of most of the renewable energy and bioenergy sources. Among the different renewable energy sources bioenergy is of crucial importance for the current and future energy supply in BY. Not only because it already has the highest share of all RES, but also due to the vast potentials of biomass and the fact that it can be used in all branches of energy sector: for HOBs, electricity or CHP generation as well as for the production of liquid biofuels. Within a supply chain available biomass can be processed and converted into the desired useful energy according to a great variety of methods and options. In order to facilitate the diffusion of the most efficient utilization paths, bioenergy policies should be designed to counteract resource competition as far as possible; both with supply-side measures and clear priorities for the most beneficial technologies and utilization paths.

The development of other branches of the renewable energy industry and energy-saving technologies (hydro and wind, especially) in BY also provides many positive effects, mainly with reference to the expected increase in energy independency, its self-sufficiency, employment, investment and production.

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